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Science Practices in the Science Learning Objects of the Greek Digital Learning Object Repository

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Abstract

Students' engagement in science practices is considered particularly important for understanding science ideas and concepts. However, research studying science practices that are engaged in science instructional material, and especially in learning objects, is rather limited. The present study aims to analyze the science learning objects of the Greek Digital Learning Object Repository that are intended for primary school with regard to the science practices engaged in them. The analysis of the learning objects used an analysis framework based on the science practices that have been proposed by the US National Research Council. (NRC, 2012). Data analysis detected the dimensions of science practices engaged in learning objects. The analysis also showed that only some dimensions of science practices are engaged in learning objects, while other dimensions of science practices, especially important for understanding science ideas and concepts, are missing.

Key words: science practices, learning objects, science education.

1. Introduction

Despite the significant progress made in the last fifteen years regarding how students learn science, research data has shown that students do not understand the basic science ideas, but instead, they memorize facts and learn to solve problems by way of habit (Shwartz, Weizman, Fortus, Krajcik, & Reiser, 2008). Consequently, the reasons why science education has not produced any satisfactory results should be investigated. In this direction, the systematic study on science teaching processes and instructional material is of great importance.

Research efforts in science education have mainly been focused on the teachers and the students rather than on the instructional material (Banilower, Smith, Weiss, Malzahn, Campbell, & Weis, 2013). This study deals with the less studied area, i.e. the instructional material. The learning process is largely shaped by the instructional material both teachers and students use during science teaching. The instructional material affects directly students' learning because the students interact with it. In addition, it indirectly affects students' learning through its effects on the teachers and their teaching choices (Moulton, 1997; Reyes, Reys, Lapan, & Holliday, 2003). As a result, the instructional material has significant effects on students' learning and, therefore, its analysis has been the object of research.

Printed instructional material prevails in instruction because it is used very frequently by the teachers, with the school textbook often being the exclusive means for science teaching (Davis, 2009; Fan & Zhu, 2007; Newton & Newton, 2006; Weiss, Nelson, Boyd & Hudson, 1989). However, in recent years, due to the development of digital technologies (Information and Communications Technologies), the use of science learning objects has been extended. Remarkable amounts of money have been invested, aiming at the development of learning objects and the creation of a Digital Learning Object Repository, which can manage collections of learning objects (Friesen, 2004). Nevertheless, the question is to what extent these learning objects can help students understand science ideas and concepts.

According to the Framework for K–12 Science Education (NRC, 2012) and the Next Generation Science Standards (NGSS Lead States, 2013), students' understanding of science ideas and concepts is based on their engagement in science practices (practices in which scientists are engaged while studying and constructing models and theories about the natural world).

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Although students' engagement in science practices is considered particularly important for their science education, there is no research examining science practices that are engaged in science learning objects. This study is focused on studying the science practices that are engaged in the science learning objects of the Greek Digital Learning Object Repository.

2. Theoretical Framework

2.1 Science Practices

Apart from knowledge, science also includes practices. "Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements –knowledge and practice– are essential" (NRC, 2012, p. 26). In recent years, it has been considered important that students also develop science practices and this has become a major objective in their science education (NGSS Lead States, 2013). Science practices are the main practices in which scientists are engaged while studying and constructing models and theories about the world (NRC, 2012). The term science practices tends to be used instead of the term science process skills in order to emphasize the fact that the engagement in scientific research requires both skills and knowledge of each practice followed. This term reflects both skills and knowledge necessary for learning and doing science (NRC, 2012).

According to the constructivist views on learning, the student does not passively acquire knowledge but actively constructs knowledge through cognitive, social and cultural processes (Duit, 2009). A basic constructivist view on learning is that the student enters the teaching process with already formed conceptions about science ideas and concepts, which are usually different from the scientific views (Driver et al., 1985). The intellectual and practical work related to processing and reviewing conceptions is based on students' engagement in science practices (NGSS Lead States, 2013). Through their engagement in science practices, the students are intended to construct and use science ideas and concepts in order to interpret phenomena, solve problems and make decisions (Duschl, Schweingruber & Shouse, 2007).

The following eight science practices have been proposed for science education (NGSS Lead States, 2013; NRC, 2012): (a) asking questions, (b) developing and using models, (c) planning and carrying out investigations, (d) analyzing and interpreting data, (e) using mathematics and computational thinking, (f) constructing explanations, (g) engaging in argument from evidence and (h) obtaining, evaluating, and communicating information. The active engagement of students in science practices can help them understand the scientific knowledge development process, construct basic science ideas and concepts, attract their curiosity and interest, and encourage them towards further research (Duschl, Schweingruber & Shouse, 2007).

2.2 Learning Objects

Apart from printed instructional material, teaching is also supported by digital instructional material. In recent years there has been heated debate about the construction of modern and effective digital instructional materials. Such materials are often described as learning objects. They are special digital entities that actually serve as educational resources for the teaching processes. The term "learning objects" first appeared in 1992 and has prevailed over other terms, such as *educational objects* (Friesen, 2001), *sharable courseware object* (Dodds, 2000), *sharable content object* (Dodds, 2001), *units of learning* (Koper, 2003) and *instructional object* (Gibbons, Nelson & Richards, 2000).

Learning objects have been attributed several definitions. A learning object is a digital entity that can be used in learning, education and training (IEEE, 2003). According to Wiley (2000), a learning object is any digital resource that can be reused in order to support learning. The learning object is a reusable entity with a clear instructional target and internal structure, accompanied by a structured amount of information that describes it so that it can more easily be found, stored and retrieved (Chiappe et al., 2007). As a result, the learning object is an autonomous and independent unit of instructional content, which is connected with one or more learning outcomes and has right from the start been developed in order to provide the opportunity to be reused in different educational frameworks.

The use of learning objects called for the creation of Digital Learning Object Repositories. Digital repositories are generally systems providing infrastructure for storing, managing, retrieving and delivering digital resources. A digital learning object repository accommodates learning objects together with suitable information about them (metadata) so that navigation and search as well as the detection and exploitation of the learning objects can become easier during the teaching process.

The creation of national learning object repositories has become a common strategy in all countries. The "Photodentro" is the central web service of the Greek Ministry of Education for collecting, organizing, effectively searching and distributing to the educational community digital educational content intended for school education. The "Photodentro" is the Greek Digital Learning Object Repository for primary and secondary education. It includes learning objects related to various subjects across the curriculum, e.g. Greek and foreign languages, mathematics, social sciences, science, geography, computer science, etc. The "Photodentro" is open to everybody, i.e. students, teachers, parents and any other party interested. It is used by the majority of them and can be found at the web address: http://photodentro.edu.gr/lor.

3. Literature Review

The research that focuses on analyzing printed science instructional material, and especially on textbooks, is particularly extensive (e.g.: Devetak & Vogrinc, 2013; Kesidou & Roseman, 2002). Furthermore, the above research has been focused on three levels: general structure, textual material and pictorial material. However, there is very little research focused on analyzing science learning objects. More specifically, frameworks within which the learning objects can be analyzed have been proposed. They can be applied in cases of existing learning objects and provide indications about their quality.

The Learning Object Review Instrument (LORI) is a framework within which the learning objects can be analyzed by their users. The users evaluate each learning object by marking it and commenting on it with regard to nine dimensions: quality of content, correlation with learning objectives, feedback and adaptation, motivations, presentation, usability of interaction, accessibility, reuse and conformity standards (Nesbit & Li, 2004; Vargo et al., 2003). The Learning Object Attribute Metric Tool (LOAM Tool) supports analyses of learning objects. With regard to the three dimensions of LOAM (environment, student's role, activity), the evaluator estimates the percentage of the learning object or of the activity of the user that falls within a number of predefined possibilities (Windle et al., 2007). The Learning Object Evaluation Metrics (LOEM) is a complicated model based on a methodical and comprehensive review of the literature on educational design (Sinclair et al., 2013). LOEM evaluates four dimensions: the levels of generalization, presentation, interactivity and organization. The Learning Object Evaluation Scale (LOES) is a tool for analyzing learning objects and is divided into two categories: one for the teachers (LOES-T) and a second for the students (LOES-S) (Kay & Knaack, 2009). After using a learning object, every teacher or student completes the LOES-T and evaluates the learning object with regard to three dimensions: learning, quality and engagement (Kay & Knaack, 2007; 2009).

Despite the fact that students' engagement in science practices is considered particularly important for understanding science ideas and concepts (NRC, 2012), there is no research studying science practices that involve science learning objects. Therefore, there is an imperative need for conducting research studying the dimensions of science practices that are engaged in science learning objects used by both teachers and students.

4. Purpose and Research Questions

The present study aims to analyze the science learning objects of the Greek Digital Learning Object Repository ("Photodentro") that are intended for primary school with regard to the science practices engaged in them. In particular, the study aims to answer the following research question: which science practices and which of their dimensions are engaged in the content of the science learning objects of the Greek Digital Learning Repository ("Photodentro") that are intended for primary school students?

5. Methodology

5.1 Research Process and Sample

This is a quantitative research study. The research process was organized in three stages. At first, the learning objects included in the "Photodentro" Greek Digital Learning Repository and intended for primary school students were concentrated. In the second stage, the framework for analyzing the learning objects was developed. Finally, in the third stage, learning objects were analyzed, data was processed and conclusions were extracted.

The research sample included the science learning objects of the Greek Digital Learning Object Repository of "Photodentro" that were intended for primary school students. Every learning object was considered an analysis unit. A total of 178 analysis units were counted.

5.2 Research Instrument

For the purposes of the present study, a framework including science practices and their individual dimensions was used (Alonzo, 2013). It was developed on the basis of the new framework for science education, which was created by the National Research Council (NRC, 2012) and the Next Generation Science Standards (NGSS Lead States, 2013). In particular, the framework of analysis that was used includes eight categories, each of them corresponding to one of the eight science practices, while each category is divided into subcategories (individual dimensions of science practices) (see Appendix).

(a) *Asking Questions*: This category includes learning objects that engage the students in the submission (formulation) and evaluation of questions.

(b) *Developing and Using Models*: This category includes learning objects that engage the students in processes of model construction and use, a "flexible movement" between different model types and the identification or evaluation of the limitations of the models, and the revision of models.

(c) *Planning and Carrying Out Investigations*: This category includes learning objects that engage the students in the formulation of questions that can be investigated, the framing of hypotheses based on models or theories, the identification of variables and the consideration as to how they can be observed or measured, the consideration of the reliability and precision of data, the observation and collection of data describing a phenomenon or testing a theory and the design or evaluation of plans for individual or collaborative research.

(d) *Analyzing and Interpreting Data*: This category includes learning objects that engage the students in the use of tables or graphs for extracting information as well as for collating, summarizing, managing or even using data as evidence and identifying the patterns in the data or the sources of the errors.

(e) *Using Mathematics and Computational Thinking*: This category includes learning objects that engage the students in the visual representation of the data, the transformation of the data between a table and a graph as well as in the statistical analysis of the data and the recognition, expression or application of quantitative relationships.

(f) *Constructing Explanations*: This category includes learning objects that engage the students in the application of explanations, the construction of explanations consistent with the evidence, the construction of reasoning, the use of evidence to support or refute an explanation and the identification of gaps or weaknesses in an explanation.

(g) *Engaging in Argument from Evidence*: This category includes learning objects that engage the students in the identification of strong and weak points in a line of reasoning about the best experimental design, the data analysis or the interpretation of a data set, the engagement in arguments in order to find the best explanation for a phenomenon, the critique of others' work, the identification of the flaws of an argument, the modification of a scientific work in light of evidence and the identification of strong and weak points in reports.

(h) *Obtaining, Evaluating and Communicating Information*: This category includes learning objects that engage the students in the oral or written communication of ideas, the communication of ideas through tables, graphs or discussions with their peers, the derivation of meanings from oral or written speech, the evaluation of the credibility of the scientific information and the integration of information from multiple sources.

5.3 Data Analysis

Learning objects were analyzed with regard to the individual dimensions of science practices, on the basis of the framework of analysis. The analysis was made by two researchers who worked independently and settled their disputes through discussions. The frequencies and the percentage frequencies (percentages) of the dimensions of the science practices that are engaged in the analyzed learning objects were identified.

6. Results

6.1 Asking Questions

Table 1 shows the frequencies and percentages of the dimensions of the science practice that is related to asking questions, which (the dimensions) are engaged in the analyzed learning objects. It was found that no learning objects engage the students in dimensions related to asking questions.

Table 1: Dimensions of the science practice that is related to asking questions in the learning objects of "Photodentro": frequencies and percentages

Asking Questions: Dimensions	f	%
Formulate empirically answerable questions	0	0
Evaluate questions for testability, relevance, and/or whether they are scientific or not	0	0
Ask probing questions about others' scientific work	0	0

6.2 Developing and Using Models

Table 2 shows the frequencies and percentages of the dimensions of the science practice that is related to developing and using models, which (the dimensions) are engaged in the analyzed learning objects. It was found that no learning objects engage the students in processes for developing and using models.

Table 2: Dimensions of the science practice that is related to developing and using models in the learning objects of "Photodentro": frequencies and percentages

Developing and Using Models: Dimensions	f	%
Construct and use models/simulations to help develop questions	0	0
Construct and use models/simulations to help develop and/or test explanations	0	0
Construct and use models to represent current understanding	0	0
Construct and use models to communicate ideas	0	0
Move flexibly between model types	0	0
Recognize limitations of models/simulations	0	0
Evaluate limitations of models/simulations	0	0
Refine models/simulations	0	0

6.3 Planning and Carrying Out Investigations

Table 3 shows the frequencies and percentages of the dimensions of the science practice that is related to planning and carrying out investigations, which (the dimensions) are engaged in the analyzed learning objects. It was found that a small number of learning objects engages the students in observation and data collection processes that describe a phenomenon (7.87%). An even smaller number of them engage the students in observation and data collection processes that test an existing theory (1.12%). There were no learning objects engaging the students in the rest of the dimensions of the science practice that is related to planning and carrying out investigations.

Table 3: Dimensions of the science practice that is related to planning and carrying out investigations in the learning objects of "Photodentro": frequencies and percentages

Planning and Carrying Out Investigations: Dimensions	f	%
Formulate a question that can be investigated	0	0
Frame a hypothesis based on a model or theory	0	0
Identify relevant variables	0	0
Consider how variables might be observed and/or measured	0	0
Consider how variables might be controlled	0	0
Consider reliability and precision of data	0	0
Observe and collect data to describe a phenomenon	14	7.87
Observe and collect data to test existing theories and explanations	2	1.12
Observe and collect data to revise and develop new theories and explanations	0	0
Design plans for investigations individually	0	0
Design plans for investigations collaboratively	0	0
Evaluate plans for investigations	0	0
Revise plans for investigations	0	0

6.4 Analyzing and Interpreting Data

Table 4 shows the frequencies and percentages of the dimensions of the science practice that is related to analyzing and interpreting data, which (the dimensions) are engaged in the analyzed learning objects. It was found that an especially small number of learning objects engages the students in the use of visualizations for collating, summarizing and managing data (1.69%) and in processes for identifying the significant features and patterns in data (1.12%). It was found that no learning object engages the students in the rest of the dimensions of the science practice that is related to analyzing and interpreting data.

Table 4: Dimensions of the science practice that is related to analyzing and interpreting data in the learning objects of "Photodentro": frequencies and percentages

Analyzing and Interpreting Data: Dimensions	f	%
Use tabulation to collate, summarize, and display data	0	0
Use graphs to collate, summarize, and display data	0	0
Use visualization to collate, summarize, and display data	3	1.69
Use statistical analysis to collate, summarize, and display data	0	0
Identify the significant features and patterns in data	2	1.12
Use data as evidence	0	0
Distinguish between causal and correlational relationships	0	0
Identify sources of error	0	0
Calculate degree of uncertainty	0	0

6.5 Using Mathematics and Computational Thinking

Table 5 shows the frequencies and percentages of the dimensions of the science practice that is related to using mathematics and computational thinking, which (the dimensions) are engaged in the analyzed learning objects. It was found that a significant number of the learning objects of "Photodentro" engage the students in a visual representation of data (38.2%), while only two learning objects engage the students in processes for recognizing quantitative relationships.

Table 5: Dimensions of the science practice that is related to using mathematics and computational thinking in the learning objects of "Photodentro": frequencies and percentages

Using Mathematics and Computational Thinking: Dimensions	f	%
Visually represent data	68	38.20
Transform data between tabular and graphical forms	0	0
Statistically analyze data	0	0
Assess the significance of patterns in data	0	0
Recognize quantitative relationships	2	1.12
Express quantitative relationships	0	0
Apply quantitative relationships and mathematical concepts	0	0
Recognize dimensional quantities and use appropriate units	0	0
Use approximation to determine whether quantitative results make sense	0	0

6.6 Constructing Explanations

Table 6 shows the frequencies and percentages of the dimensions of the science practice that is related to constructing explanations, which (the dimensions) are engaged in the analyzed learning objects. It was found that only one learning object engages the students in processes for constructing explanations about the phenomena that are consistent with evidence. No learning objects were detected engaging the students in the rest of the dimensions of the science practice that is related to constructing explanations.

Table 6: Dimensions of the science practice that is related to constructing explanations in the learning objects of "Photodentro": frequencies and percentages

Constructing Explanations: Dimensions	f	%
Apply standard explanations of phenomena	0	0
Incorporate current understanding of science into explanations	0	0
Construct explanations of phenomena consistent with evidence	1	0.56
Link evidence to claims	0	0
Use evidence to support or refute an explanatory account	0	0
Identify gaps or weaknesses in explanatory accounts	0	0

6.7 Engaging in Argument from Evidence

Table 7 shows the frequencies and percentages of the dimensions of the science practice that is related to engaging in argument, which (the dimensions) are engaged in the analyzed learning objects. It was found that very few learning objects engage the students in processes for identifying the reasoning of the claims made by the scientific community (5.06%), processes for engaging in argument in order to find the best explanation for a phenomenon individually (1.69%) as well as in processes for identifying the weaknesses in an argument (0.56%). No learning objects were detected engaging the students in the rest of the dimensions of the science practice that is related to engaging in argument.

Table 7: Dimensions of the science practice that is related to engaging in argument in the learning objects of "Photodentro": frequencies and percentages

Engaging in Argument from Evidence: Dimensions	f	%
Engage in reasoning and argument to identify strengths and weaknesses in a line of reasoning about the best experimental design	0	0
Engage in reasoning and argument to identify strengths and weaknesses in a line of reasoning about the most appropriate techniques of data analysis	0	0
Engage in reasoning and argument to identify strengths and weaknesses in a line of reasoning about the best interpretation of a given data set	0	0
Formulate evidence based on data	0	0
Engage in reasoning and argument to identify strengths and weaknesses in a line of reasoning about how data supports a claim		0
Engage in reasoning and argument to find the best explanation for natural phenomena individually	3	1.69
Engage in reasoning and argument to find the best explanation for natural phenomena collaboratively	0	0
Analyze arguments to determine whether they emphasize similar or different evidence and/or interpretations	0	0
Provide critiques of others' scientific work	0	0
Identify flaws in one's own arguments	1	0.56
Modify one's own scientific work in light of evidence	0	0
Modify one's own scientific work in response to critiques	0	0
Understand how claims are judged by the scientific community	9	5.06
Identify strengths and weaknesses in media reports of science	0	0

6.8 Obtaining, Evaluating, and Communicating Information

Table 8 shows the frequencies and percentages of the dimensions of the science practice that is related to obtaining, evaluating and communicating information, which (the dimensions) are engaged in the analyzed learning objects. It was found that a small number of the learning objects of "Photodentro" engage the students in processes for deriving the meaning from scientific papers, processes for communicating ideas through tables and graphs or discussions with peers, processes for orally communicating ideas as well as in processes for integrating information from multiple sources. No learning objects were detected engaging the students in the rest of the dimensions of the science practice that is related to obtaining, evaluating and communicating information.

Table 8: Dimensions of the science practice that is related to obtaining, evaluating and communicating information in the learning objects of "Photodentro": frequencies and percentages

Obtaining, Evaluating, and Communicating Information: Dimensions	f	%
Communicate ideas orally	12	6.74
Communicate ideas in writing		
Communicate ideas with the use of tables, diagrams, graphs, and equations	14	7.87
Communicate ideas through extended discussions with peers	0	0
Derive meaning from scientific papers	16	8.99
Derive meaning from scientific texts from the Internet	0	0
Derive meaning from scientific information presented orally	0	0
Identify flaws in reports about science in the press or on the Internet	0	0
Evaluate the validity of scientific information	0	0
Assess the credibility of sources of scientific information	0	0
Assess the accuracy of sources of scientific information	0	0
Assess possible bias in sources of scientific information	0	0
Integrate information from multiple sources	4	2.25

7. Discussion and Conclusions

The present study showed that only some science practices, and especially some of their dimensions, are engaged in the analyzed primary school science learning objects of the "Photodentro" Greek Digital Learning Object Repository, while other science practices and their dimensions are missing.

More specifically, the science practice of asking questions seems to be completely missing from the learning objects that were analyzed. However, it has been underlined that students' asking questions greatly contributes to the learning process because it can activate their initial conceptions and help them change their knowledge (Chin & Osborne, 2008).

In addition, the science practice of developing and using models is completely missing from the learning objects that were analyzed. Nevertheless, according to Ainsworth et al. (2011), the development and the use of models by the students, their acquaintance with the conventions that accompany them and with their function, could contribute to their understanding of the phenomena for which these models have developed. Furthermore, the use of models helps the students formulate scientific questions, construct explanations and communicate their ideas (Nersessian, 2008).

The dimensions of science practices that are related to planning and carrying out investigations as well as to data analysis are engaged in a very small number of science learning objects. In particular, they are dimensions mainly related to the observation and collection of data that describes a phenomenon. But there are no dimensions related to asking a question that can be investigated, framing a hypothesis, identifying variables, considering how the variables can be observed, measured or controlled as well as to considering the reliability and the precision of data, designing and evaluating research plans, either individually or collaboratively, using tables, graphs and statistical analysis for contrasting, summarizing and managing data, using data as evidence and identifying the sources of errors.

It has been underlined that understanding science ideas and concepts requires that the students be engaged in the stages of scientific research and its progress (OECD, 2013). Furthermore, the above dimensions are also considered necessary in order to understand the nature of science (NRC, 2102). Besides, the engagement of students in designing and conducting investigations as well as in analyzing and interpreting data contributes to the development of their ability to produce documented explanations (NRC, 2012; Skoumios, 2012).

As for the science practice related to mathematics and computational thinking, it was found that some of its dimensions are engaged in a particularly small number of analyzed learning objects. More specifically, these dimensions are mainly related to the visual representation of data rather than to the recognition of quantitative relationships. However, there are no dimensions related to the transformation from one type of data representation to another (e.g. from table to graph), to the expression or application of quantitative relationships as well as to the statistical analysis of data. As Orton and Roper (2000) have underlined, the dimensions of this practice contribute to the deeper understanding of science ideas and concepts.

With regard to the science practice of constructing explanations, it seems that the learning objects lack crucial dimensions, such as the explanations of the phenomena, the link between evidence and claims, the use of evidence to support or refute an explanation and the identification of gaps or weaknesses in an explanation. The above dimensions are main elements of students' science education (NRC, 2012). The process of constructing scientific explanations could help the students better understand the content and the nature of science (Sandoval & Reiser, 2004).

The science practice related to engaging in an argument based on evidence rarely appears in the analyzed learning objects. Very few learning objects engage the students in dimensions related to the way in which the claims are judged by the scientific community and in a line of reasoning or argument in order to collaboratively find the best explanation for a natural phenomenon. However, engaging in an argument based on evidence is considered a main element of science education (NRC, 2012) and constitutes an essential dimension of scientific literacy (OECD, 2013). Moreover, engaging in argument is by all means necessary not only for those who intend to actively delve into a scientific field but for all the citizens. Citizens should critique written scientific data presented to them on the Internet or in newspapers and magazines, and oral scientific data presented on the television or the radio (McNeill & Krajcik, 2012). They should have developed the ability to evaluate arguments, determine whether the claims are based on evidence and whether the reasoning included in them is sufficiently documented. Besides, engaging in argument could contribute to students' better understanding of science content (Sandoval & Reiser, 2004).

As for the science practice related to obtaining, evaluating and communicating information, it was found that some of its dimensions are engaged in a small number of learning objects. No learning objects engaging all the dimensions of this practice were detected. These dimensions are considered important for science education (Pearson et al., 2010).

Therefore, it is concluded that most of the learning objects that were analyzed do not engage the students in science practices. Furthermore, it emerges that the few learning objects engaging the students in science practices finally engage them in only a few dimensions of these science practices, while other dimensions, particularly important for learning science ideas and concepts, are missing.

This study was focused on investigating science practices that are engaged in science learning objects intended for primary school students of the Greek Digital Learning Object Repository. In order to form a more complete picture of the science practices in which Greek students are engaged, the learning objects that are intended for secondary education should also be analyzed. Furthermore, the analysis of learning objects of digital learning object repositories of other countries and the comparison of results would be of particular research interest.

This study was centered on only the analysis of learning objects rather than on their application within the school framework. Further research is required so that the effect of the application of learning objects on students' science practices can systematically be studied.

In conclusion, further research is required so that science learning objects engaging several dimensions of science practices can be constructed and the effect of their application on both the development of science practices and students' understanding of science ideas and concepts can be studied.

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Appendix

Science Practices and their Dimensions

Science Practices	Dimensions
Asking Questions	Formulate empirically answerable questions Evaluate questions for testability, relevance, and/or whether they are scientific or not Ask probing questions about others' scientific work
Developing and Using Models	Construct and use models/simulations to help develop questions Construct and use models/simulations to help develop and/or test explanations Construct and use models to represent current understanding Construct and use models to communicate ideas Move flexibly between model types Recognize limitations of models/simulations Evaluate limitations of models/simulations Refine models/simulations
Planning and Carrying Out	Formulate a question that can be investigated Frame a hypothesis based on a model or theory

Investigations	Identify relevant variables Consider how variables might be observed and/or measured Consider how variables might be controlled Consider reliability and precision of data Observe and collect data to describe a phenomenon Observe and collect data to test existing theories and explanations Observe and collect data to revise and develop new theories and explanations Design plans for investigations individually Design plans for investigations collaboratively Evaluate plans for investigations Revise plans for investigations
Analyzing and Interpreting Data	Use tabulation to collate, summarize, and display data Use graphs to collate, summarize, and display data Use visualization to collate, summarize, and display data Use statistical analysis to collate, summarize, and display data Identify the significant features and patterns in data Use data as evidence Distinguish between causal and correlational relationships Identify sources of error Calculate degree of uncertainty
Using Mathematics and Computational Thinking	Visually represent data Transform data between tabular and graphical forms Statistically analyze data Assess the significance of patterns in data Recognize quantitative relationships Express quantitative relationships Apply quantitative relationships and mathematical concepts Recognize dimensional quantities and use appropriate units Use approximation to determine whether quantitative results make sense
Constructing Explanations	Apply standard explanations of phenomena Incorporate current understanding of science into explanations Construct explanations of phenomena consistent with evidence Link evidence to claims Use evidence to support or refute an explanatory account Identify gaps or weaknesses in explanatory accounts
Engaging in Argument From Evidence	Engage in reasoning and argument to identify strengths and weaknesses in a line of reasoning about the best experimental design Engage in reasoning and argument to identify strengths and weaknesses in a line of reasoning about the most appropriate techniques of data analysis Engage in reasoning and argument to identify strengths and weaknesses in a line of reasoning about the best interpretation of a given data set Formulate evidence based on data Engage in reasoning and argument to identify strengths and weaknesses in a line of reasoning about how data supports a claim Engage in reasoning and argument to find the best explanation for natural phenomena individually Engage in reasoning and argument to find the best explanation for natural phenomena collaboratively Analyze arguments to determine whether they emphasize similar or different evidence and/or interpretations Provide critiques of others' scientific work Identify flaws in one's own arguments Modify one's own scientific work in light of evidence

	Modify one's own scientific work in response to critiques Understand how claims are judged by the scientific community Identify strengths and weaknesses in media reports of science
Obtaining, Evaluating, and Communicating Information	Communicate ideas orally Communicate ideas in writing Communicate ideas with the use of tables, diagrams, graphs, and equations Communicate ideas through extended discussions with peers Derive meaning from scientific papers Derive meaning from scientific texts from the Internet Derive meaning from scientific information presented orally Identify flaws in reports about science in the press or on the Internet Evaluate the validity of scientific information Assess the credibility of sources of scientific information Assess the accuracy of sources of scientific information Assess possible bias in sources of scientific information Integrate information from multiple sources